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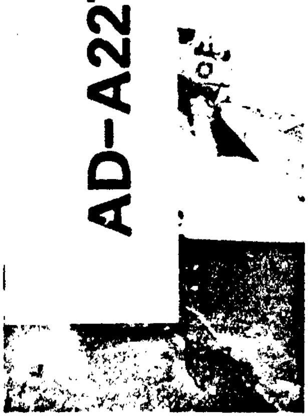

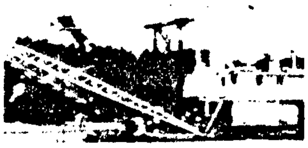

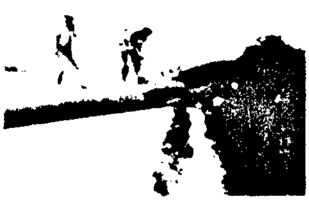

DREDGING OPERATIONS TECHNICAL SUPPORT PROGRAM

TECHNICAL REPORT D-90-12

GUIDELINES FOR PHYSICAL AND BIOLOGICAL MONITORING OF AQUATIC DREDGED MATERIAL DISPOSAL SITES

by

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This report is a preliminary set of guidelines for physical and biological monitoring of aquatic uncontaminated dredged material disposal sites. The need for guidelines on this subject was one of the items identified at the August 1985 Long-Term Management Strategy Workshop sponsored by the Water Resources Support Center. The resulting guidelines are intended to serve as a "working" document that can be periodically improved as experience dictates.

Emphasis is placed on the establishment of concise objectives and hypotheses, the use of multidisciplinary approaches to developing monitoring programs, and the provision of results that are relevant and useful to site managers.

A "tiered" step-wise procedure to develop a monitoring program is presented, along with a summary of the basic tools and techniques for biological and physical analyses.

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More detailed information is available in "Selected Tools and Techniques for Physical and Biological Monitoring of Aquatic Dredged Material Disposal Sites" (Technical Report D-90-11). (JS)

Ideally, monitoring of open-water dredged material disposal sites should be prospective. In prospective programs, specific desirable and undesirable conditions are clearly defined prior to sampling. Observations or measurements are taken to determine if site conditions conform to these defined conditions. The resulting monitoring can thus focus on the detection of changes in specific conditions rather than identifying any or all detectable changes.

A monitoring program should be multitiered, with each level (tier) having its own predetermined environmental threshold, hypothesis, sampling design, and management option(s) should the threshold be exceeded. Each tier would have an increasing predetermined intensity (threshold). If a threshold is not exceeded, the next tier of monitoring would not be needed. If a threshold is exceeded, the next tier of monitoring would be triggered. In addition, this provides an "early warning" system for detection of predetermined "adverse effects." This early-warning system allows site managers to make modifications in operations (e.g., capping a disposal site with clean sand) before an unacceptable impact occurs.

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PREFACE

These guidelines were prepared as part of the Dredging Operations Technical Support (DOTS) Program at the US Engineer Waterways Experiment Station (WES). The DOTS Program is sponsored by the Headquarters, US Army Corps of Engineers (HQUSACE), and is managed by the WES Environmental Laboratory (EL) through the Environmental Effects of Dredging Programs (EEDP). Dr. Robert M. Engler was Program Manager for the EEDP; Mr. Thomas R. Patin was the DOTS Program Manager. Mr. Joseph Wilson was the HQUSACE Technical Monitor.

This report was prepared by Dr. Thomas J. Fredette and Mr. David A. Nelson of the Coastal Ecology Group (CEG), Environmental Resources Division (ERD), EL, and by Mr. James E. Clausner and Mr. Fred J. Anders of the Coastal Structures and Evaluation Branch (CD-S), Engineering Development Division (CD), Coastal Engineering Research Center (CERC). Dr. Thomas W. Richardson and Mr. Edward B. Hands of the CERC and Messrs. Edward J. Pullen and David A. Nelson of the EL served as technical reviewers. Dr. Mark W. LaSalle, CEG, edited and provided information for the biological portions of the report. The report was edited for publication by Ms. Jessica S. Ruff of WES Information Technology Laboratory.

The CEG personnel worked under the direct supervision of Mr. Edward J. Pullen, Chief, CEG, and under the general supervision of Dr. Conrad J. Kirby, Chief, ERD, and Dr. John Harrison, Chief, EL. The CD-S personnel worked under the direct supervision of Ms. Joan Pope, Chief, CD-S, and under the general supervision of Dr. Thomas W. Richardson, Chief, CD, and Dr. James R. Houston, Chief, CERC.

Commander and Director of WES was COL Larry B. Fulton, EN. Technical Director was Dr. Robert W. Whalin.

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CONTENTS

GUIDELINES FOR PHYSICAL AND BIOLOGICAL MONITORING OF AQUATIC DREDGED MATERIAL DISPOSAL SITES

PART I: INTRODUCTION

1. Monitoring of aquatic dredged material disposal sites should not be viewed as an isolated activity but as one of several interacting components of an overall dredged material management framework, which includes site designation, project evaluation, and regulatory permitting, compliance, and enforcement. As part of the dredged material site designation process, a prospective monitoring plan is used in reaching decisions on site location and size. One goal of site designation is to select a site with the least potential for adverse environmental effects, thus minimizing monitoring requirements. Too much monitoring is a waste of time and money. Too little monitoring allows for undetected environmental effects and provides inadequate information for managing a site.

2. This document recommends an approach to a monitoring program design which emphasizes results that are useful to dredged material disposal site managers. The report focuses on dredged material determined suitable for open-water disposal; therefore, the report does not consider lethal or sublethal effects of toxic substances. However, in cases where contaminants are of concern, the monitoring strategy outlined herein can be used, but with the appropriate sampling techniques for such materials incorporated in the study design. Monitoring of contaminated dredged material is addressed in a report by Pequegnat and Gallaway (1990).

3. The monitoring approach described in this report has application for either dispersive or nondispersive disposal sites, since in both cases adverse anthropogenic effects outside the designated disposal site are to be avoided. Nondispersive sites are chosen with the intention that most or all of the disposal material remains where it is placed, thus having only limited areal impact. Dispersive sites are chosen with the intent that transport and dilution of the disposed material will occur, but that this transport will not occur at a rate detrimental to the marine environment outside the designated disposal site. A dispersive site by definition receives material that is dispersed at undetectable levels and locations. Monitoring of dispersed material is generally not feasible or practicable because it cannot be detected at low

levels. Natural sediment processes are often so large that disposed material contributions to the system are insignificant in comparison. Thus, a negative environmental effect would not be produced.

4. This report provides guidance on monitoring aquatic dredged material disposal sites. A separate report provides information on selected tools and techniques that can be used in various monitoring programs (Fredette et al. 1990).

Monitoring As a Component of Dredged Material Management

5. Each component of the dredged material management framework is integral to the overall management objectives, as it either provides background information for subsequent components or generates information that can be used in a feedback loop to modify the approach taken in the future. For example, information learned about toxicity of certain sediments in the project evaluation phase can be used to modify the design of future projects from the area where the toxic sediments originate. Because of the interactive and supporting roles of the various components, the development of monitoring plans must be based on the contributions and conclusions each brings to the framework, particularly the site designation and project evaluation components.

6. In particular, monitoring should be used as a powerful management tool to provide specific evidence that can be used in a feedback loop to support or modify other components of the framework. In this fashion, an assessment of decisions that were made when a site was designated or when a project was permitted can lead to verification of assumptions or predictions, or can be used as a basis for modifying the decision process (either development of more or less stringent decision guidelines).

Site designation

7. The site designation documents, such as Environmental Assessments (EA) or Environmental Impact Statements (EIS), which were developed to guide the decision on site designation/selection, should be used to identify appropriate monitoring objectives for a site. The EA/EIS developed for the site described the impacts expected to occur as a result of site use, identified nearby sensitive resources, and described what issues were judged to be insignificant. Where appropriate, the monitoring plan should be used to verify the impact predictions and support assumptions that led to site selection. Unless

there is strong technical evidence that has arisen since the EA/EIS, a monitoring plan should not include aspects that would deviate from the findings or recommendations of the selection/designation documents.

8. As a consequence of the site designation/selection process, it is also reasonable to expect that monitoring of the disposal site is a minimal requirement. Although the siting of a disposal area results from the consideration of a matrix of environmental, operational, and economic factors, the final designation should result in the choice of a site that has limited potential for impact (located away from sensitive habitats, spawning areas, etc.) and therefore requires only limited monitoring.

9. The individual responsible for monitoring program design and implementation may find that the District/Division's disposal site(s) fall into one of three categories: the site is a historically used Section 404* site and an EA or EIS does not exist, the site is an interim Section 103** site and the EA/EIS has not been completed, or the site has been designated/selected through the EA/EIS process. In the first example, National Environmental Protection Act documentation will not be available to support the Corps decision on the adequacy of a monitoring plan. Nevertheless, the focus of the plan should be toward support of site selection and project evaluation decisions. In the second and third situations, the EA/EIS documents in preparation or completed should serve as the basis of the Corps recommended plan (sensu the Federal Standard).

10. The interaction between monitoring and site designation/selection should also be viewed from another perspective, as monitoring considerations should play a role in the site designation process. During consideration of the factors that will influence site selection/designation (for example, the 5 general and 11 specific criteria of the Ocean Dumping Regulations), the practicality and interpretability of the future monitoring plan should be incorporated. If a site is chosen for which monitoring is operationally and technologically difficult, the ability to actively manage the site and to meet the requirements of the regulations will be lost. Indeed for Section 103 designations, monitoring considerations are one of the specific 11 criteria that must be factored into the final site selection decision.

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* Federal Water Pollution Control Act Amendments of 1972.
** Marine Protection, Research, and Sanctuaries Act of 1972.

11. Development of the site designation/selection field study would also benefit from consideration of what monitoring will later be necessary. Frequently, the site evaluation field studies include the collection of large quantities of baseline environmental information. If preliminary outlines of the monitoring plan are developed at this time, field collection efforts could focus on collecting those data types that will be most useful once monitoring does begin. The effort expended at this stage will greatly increase the site manager's ability to assess long-term cumulative impacts.

Project evaluation

12. The evaluation of dredging and disposal projects through both the Corps planning process and the regulatory permitting process also serves to eliminate the need for extensive monitoring at the disposal site. Through the project evaluation process, sediments to be disposed may be tested for (a) the concentration of various organic and inorganic contaminants, (b) toxicity, and (c) the potential for bioaccumulation. As a result of the outcome of these tests and other considerations, a decision is made whether the sediment is likely to cause unacceptable adverse effects if disposal at the site were permitted. If the material is judged to be suitable for unconfined open-water disposal (no effects expected), there should be little concern, and the need for monitoring should be minimal.

13. The monitoring scheme should be designed to verify and support decisions made in the project evaluation phase that sediments are suitable for unconfined open-water disposal. Given the extensive Corps experience with toxicity and bioaccumulation testing for sediment evaluation and the conservative nature of tests as demonstrated in the Field Verification Program (Peddicord 1988), such follow-up monitoring need not be frequent or extensive.

14. Use of this approach will allow for development of greater confidence in project evaluation methods used (i.e., bioassay and bioaccumulation tests), as monitoring results lead to either verification or modification of evaluation guidelines. As greater experience is gained through these feedback loops, the amount of project evaluation testing and disposal site monitoring could be reduced.

Background

15. One of the items identified at the Long-Term Management Strategy Workshop in August 1985 was the need for guidelines on monitoring aquatic

dredged material disposal sites. Based on that need, the Water Resources Support Center sponsored, through the Dredging Operations Technical Support Program, a task to produce combined biological and physical guidelines for use in monitoring programs. The draft guidelines presented herein are the product of that task. The US Army Engineer Waterways Experiment Station (WES) encourages the Corps Districts to use these guidelines over the next several years and provide to WES their comments on suggested changes and improvements. A large portion of the material presented in these guidelines came from the results of the Disposal Area Monitoring System and Field Verification Programs.

16. The US Army Corps of Engineers (USACE) and the US Environmental Protection Agency (USEPA) share the responsibility of designating dredged material disposal sites and ensuring that disposal does not result in degradation of the marine environment (Gordon et al. 1982, USACE 1984). This responsibility is meant to ensure that: (a) human health is not endangered, (b) the status of marine resources is known and not degraded, and (c) disposal site status is known so that modifications as to its use can be made (Committee on Public Works 1973, Segar and Stamman 1986a,b).

17. Federal laws and regulations such as the Federal Water Pollution Control Act Amendments of 1972, the Marine Protection, Research, and Sanctuaries Act of 1972, the Clean Water Act (Committee on Public Works 1973), and the USEPA Ocean Dumping Regulations* were passed to ensure environmental protection. However, although made in the best interest and intention of environmental protection, these laws are often vague or ambiguous. Federal regulations often define harmful environmental impact as "unacceptable" adverse effects and "unreasonable" degradation (Committee on Public Works 1973; see also Federal Register*). There is a need to develop monitoring techniques for which specific "adverse effects" are clearly defined, thereby creating an "early-warning" program designed to successfully protect marine resources rather than detect their degradation.

18. Monitoring of open-water dredged material disposal sites is conducted to investigate physical, chemical, and biological impacts on resources of concern. Potential physical impacts arise from the behavior of the disposal material, and include mounding, transport of material out of the disposal site to undesirable locations such as shellfish beds, beaches, or navigation channels, and effects of disposal mounds on hydrodynamic processes

* Federal Register, Vol 42, No. 7 (1977).

such as wave refraction and currents. Potential chemical impacts are related to direct and indirect toxicity impacts on both marine organisms and humans as a result of sediment-associated chemical contamination. The effect of dredged material disposal from a biological perspective usually involves monitoring for impacts to specific resources (e.g., hard clams) or general changes in community structure and function. However, biological changes will also reflect responses to either physical or chemical alterations. Because disposal site management depends on proper monitoring to determine site status, successful monitoring programs must integrate physical, chemical, and biological data into interpretable results that can be used by a site manager to make decisions about site use.

19. Disposal programs in which monitoring design has been inadequate often monitor traditional parameters such as water column and sediment chemistry, hydrographic conditions, benthic infaunal community structure, and fish, phytoplankton, and zooplankton populations (Gordon et al. 1982; Segar 1985; Segar, Stamman, and Davis 1989). Such data frequently are not clearly interpretable to managers and provide little insight for decisions regarding site status, usually because of an initial lack of consideration given to how the results are to be applied or against what standards the data will be compared. Resource objectives are usually not specified, and no attempt is made to define what would constitute a "significant" impact to the environment.

20. This document recommends an approach to monitoring program design which emphasizes results that are useful to site managers. The report focuses on dredged material certified for open-water disposal (e.g., relatively uncontaminated) and therefore does not consider lethal or sublethal effects of toxic substances. However, in cases where contaminants are of concern, the monitoring strategy outlined herein can be used, with the appropriate sampling techniques for such materials implemented into the study design.

21. The monitoring approach described in this report has application for either dispersive or nondispersive disposal sites, as in both cases adverse anthropogenic effects outside the designated disposal site are to be avoided. Nondispersive sites are chosen with the intention that most or all of the disposal material remains where it is placed, thus having only a limited areal impact. Dispersive sites are chosen with the intent that transport of the disposed material will occur, but that this transport will not occur at a rate detrimental to the marine environment outside the designated disposal site.

22. Site designation is usually viewed as a separate process whereby site location and size are determined by evaluating political, social, and environmental concerns. However, in many instances the site may be designated with insufficient attention given to a prospective monitoring program to protect the environmental concerns (e.g., hard clams, oyster beds, etc.). Consideration of monitoring programs during the site designation phase may be useful in reaching decisions about factors such as site location and size.

23. This report provides information on general concepts for approaching monitoring requirements, statistical design considerations, and descriptions of sampling equipment and techniques for both physical and biological parameters.

PART II: OBJECTIVES OF MONITORING

24. The purpose of monitoring is to document whether impacts defined as unacceptable are occurring, or whether conditions that will lead to an unacceptable impact are developing. A monitoring program should provide the site manager with clearly interpretable information about whether a threshold of adverse condition has been reached or is likely, so that decisions about continued or modified site use can be made.

25. Monitoring may be prospective or retrospective. Ideally, monitoring, as it applies to management of open-water dredged material disposal sites, should be prospective, consisting of repeated observations or measurements that determine if site conditions conform to an "already stated standard" (Moriarty 1983). Conversely, in retrospective programs the magnitudes, types, and areal extent of adverse impacts are not defined until after sampling is under way and data are being interpreted. Unfortunately, this is the approach most monitoring programs usually follow. As a result, it is frequently discovered that the proper questions were not asked or addressed, thereby producing ambiguous results.

26. In a prospective program, specific desirable and/or undesirable conditions (e.g., unacceptable adverse effects or unreasonable degradation) are clearly defined <u>before</u> sampling is begun. Further, it is necessary to predict what resources at or near the disposal site are at risk and what magnitude and extent of impact could possibly result from disposal. It is very important that the development of predictions involve consideration of how and at what thresholds physical and chemical changes (cause) will result in undesirable biological responses (effect). Thus, resources of concern are clearly identified, <u>specific thresholds</u> of conditions (physical, chemical, or biological) that should not be exceeded are stipulated, and potential (e.g., worst-case) impacts of disposal activities are predicted. Consequently, the development of a sampling program can focus on detection of changes in specific conditions rather than simply looking for <u>any</u> detectable change (Green 1984). Any data that are collected, therefore, must be applicable to addressing a specific question. Once disposal has begun and monitoring results are available, the disposal site manager will have clear guidance on whether problems are evident and if site use needs to be modified.

27. A prospective monitoring program is more difficult to design than one that is retrospective. It is not sufficient to exclaim that one is

concerned about a resource (e.g., surf clams) and to state that they should be monitored. A prospective program requires that changes in resources at risk be quantified and that the threshold at which changes become unacceptable be explicitly specified.

PART III: SYSTEMATIC MONITORING PROGRAM

Tiered Approach/Hypothesis Testing

28. The design of a management-response prospective program requires a systematic approach following these general steps: (a) evaluation of managerial needs and objectives for site use and (b) implementation of a prospective monitoring program. The monitoring program should be multitiered with each level having its own unacceptable environmental threshold, null hypothesis, sampling design, and management option(s) should the environmental threshold be exceeded. Design of the program should be the product of a multidisciplinary planning group that would allow for a more thorough examination of the wide range of factors that must be considered. A proper design can be achieved following Green's (1984) systematic approach:

> Purpose > Question > Hypothesis (e.g., predetermined threshold) > Model > Sampling design > Statistical analysis > Tests of hypotheses > Interpretation and presentation of results

29. It must be emphasized that defined objectives predetermine the statistical analyses used, not the reverse (Green 1984). Fredette et al. (1986) and Segar and Stamman (1986a,b) provide discussions of the effects of spatial and temporal variation in the development of a tiered prospective monitoring program. In a tiered approach, each objective is monitored by testing a series of null hypotheses or tiers, each at a different predetermined level of intensity. Results that indicate acceptance of the null hypothesis at the first level or tier would prevent further, more costly monitoring at a more complex level. Results that indicate rejection of the null hypothesis would trigger monitoring at higher tiers, thus providing an early-warning system for detection of the predetermined adverse effect. Such a multitiered approach would allow time for managers to make modifications in disposal operations before a significant impact had occurred. The tiered approach would also allow time for consideration of cost-effectiveness.

30. The following set of examples serves to contrast the design of a tiered monitoring program with that of a nontiered program and demonstrates how the aforementioned advantages could be realized as the result of a tiered approach.

Program without tiers

31. Assume that a monitoring program is to be developed for a recently designated offshore disposal site somewhere in the Northwest Atlantic. The initial objective is to designate the resource(s) that are to be protected (e.g., fishery resources, recreational resources, human health, endangered species). In this case, assume that during initial planning it has been determined that only one resource, a substantial surf clam population living at a water depth of 30 m, exists in proximity to the disposal area and is judged to be at risk. Hence, the overall purpose of the program is directed toward ensuring that disposal will have no unacceptable adverse biological effect (e.g., decrease in population density) on the surf clam resource. With this purpose in mind, it is possible to follow Green's (1984) protocol and design the following program.

> Question: Will deposited sediments have an unacceptable, adverse biological effect on the population density of the surf clam?
>
> Null hypothesis (Ho): The changes in mean density of surf clams at various locations are unrelated to changes in mean sediment particle size subsequent to disposal.

If statistical analysis, hypothesis testing, and interpretation of results lead to rejection of the null hypothesis (hence, there has been an unacceptable disposal-induced effect on population density), the logical management decision would be either to abandon or relocate the disposal site. Unfortunately, the design of the program, directed at the changes in the resource, would provide for the management decision to be made only after the resource impact reached an unacceptable level (a significant decrease in population density).

Program with tiers

32. Use of an alternative tiered approach with early-warning tiers would allow program designers and managers to determine if resources of concern are being adversely affected. Design of early-warning tiers requires information about (a) surf clam biology (particularly that pertinent to potential impacts of suspended and deposited sediments), (b) regional hydrodynamics that could allow for prediction of near-bottom dredged material and water transport, and (c) the disposal activity anticipated, especially with regard to sediment characteristics, disposal periodicity, and seasonality. This information would then be used to predict the potential impacts of the disposal activities. Such predictions can be used to formulate several testable

hypotheses to be incorporated into the tiers of the monitoring program. Since the literature reveals that surf clams are best suited to coarse-grained habitats (Fay, Neves, and Pardue 1983), it might be expected that reductions in sediment grain size in the population's habitat, which could occur as a result of deposition of fine-grained sediments, would be detrimental. Predictions related to transport of disposed sediment to the population's habitat could lead to formulation of the following conservative null hypothesis (Ho) for the first tier of the study.

> Tier 1-Ho: Mean sediment grain size at the site where surf clam populations exist remains unchanged subsequent to disposal. The critical threshold for the tier would be a doubling in fines (silt/clays) relative to baseline (from 5 to 10 percent fines), which has been predicted to be adverse and has been established as the threshold for this tier.

33. An inexpensive sampling program (relative to that required for the hypothesis proposed earlier in the nontiered approach) designed for testing such a hypothesis could yield data that would be available to project managers very quickly. If monitoring results support acceptance of the null hypothesis, implementation of more intensive monitoring would be unnecessary since there would be no documentation of sediment transport to the study site. However, if the null hypothesis were rejected, at least two actions could be taken: (a) project management options to alleviate the observed impacts could be exercised (for example, a capping program where sand is layered over finer material or scheduling of disposal events so as not to coincide with periods of unsettled weather might be deemed appropriate) or (b) the monitoring program could proceed to the subsequent tier.

34. The sequence of tiers appropriate for the present example could be as follows:

- a. Tier 2-Ho. Condition index (ratio of internal shell volume to tissue volume) of surf clams is not negatively affected by observed changes in sediment grain size (e.g., decreasing below 5.0 based on mean of 30, 2-year-old individuals sampled quarterly).
- b. Tier 3-Ho. The changes in mean density of surf clams (e.g., below a threshold of 1 per square metre within the designated region based on annual fall sampling at 25 stations and compared to baseline values) at various locations are unrelated to changes in mean sediment particle size subsequent to disposal.

35. Implicit in this type of approach is the idea that each tier will have its own predicted critical threshold, null hypothesis, and sampling design; rejecting the null hypothesis proposed for one tier will automatically

trigger the more intensive monitoring program at the next tier. Thus, the intensity (e.g., effort and therefore cost) of monitoring should be commensurate with the effects anticipated.

36. The first and subsequent tiers of the monitoring program (as above) may not involve any biological sampling. This may be especially true when cause-and-effect relationships are well known. However, even if cause-and-effect relationships are not well known, a physical or chemical sampling program based on predictions of potential impacts and the mechanisms through which these impacts will result should almost always serve as a first tier of monitoring (Segar, Stamman, and Davis 1989).

37. Designers of tiered monitoring programs must make a priori decisions regarding the tier and magnitude of impact at which consideration of site closure will be appropriate. For example, whereas some minimal level of change in sediment characteristics, condition index, or population density might be considered acceptable, a substantial (50-percent) disposal-related reduction in mean population density, for example, might be unacceptable.

Use of a Multidisciplinary Committee

38. The tiered prospective monitoring approach requires a considerable amount of prior planning and technical expertise, especially in contrast to that required by retrospective programs. It is necessary to consider a variety of factors in the design of a monitoring program. These factors include information on the value of habitat areas as perceived by local interests, predictions of disposal material behavior, predictions of potential impacts, and determination of specific adverse levels of impact and thresholds of concern. One of the best ways to accomplish these necessary tasks is through a multidisciplinary committee of technical advisors. In addition to being charged with the responsibility of designing the monitoring program, the technical committee should interact on a regular basis with project managers to provide sound advice that is both reasonable (especially in consideration of real-world budgets) and environmentally relevant.

39. The committee should be composed of individuals with a composite experience and knowledge of regional environmental conditions and resources, hydrodynamics and sediment transport, information needs of site management, suspended and deposited sediment effects on organisms, lethal and sublethal effects of sediment-associated chemicals on organisms, and sampling program

design and execution. Depending on the particular situation, such a committee might involve only Corps representatives, or it may be appropriate to include non-Corps advisors. Committee membership should be kept to a minimum (eight individuals or fewer) in the interest of both coordination and efficiency. The committee chairperson should be responsible for focusing the committee's efforts and ensuring that decisions are reached when adequate information is available or when additional (though not critical) desired information could be obtained only through added effort. Dissenting and minority opinions that develop during the committee's deliberations should be expressed in written reports to the project manager to highlight the areas that are most equivocal.

Program Flexibility

40. The level of effort devoted to monitoring should be related to the magnitude and types of concerns. In some cases there may be little or no need to conduct monitoring. Such situations may include sites that have been used historically with no problems, sites where the disposal sediments are similar to the natural sediments (e.g., sand on sand, mud on mud), sites that are used infrequently, or sites that receive only small volumes of material. In other situations, monitoring requirements range from a need for only physical monitoring to consideration of a large suite of physical, chemical, and biological investigations.

41. Flexibility in monitoring approaches, frequency, and intensity will improve overall program implementation and usefulness. When designing a program it is usually easier and less expensive to provide for more intensive sampling (more stations, replicates, or sampling techniques) than to increase the frequency of sampling, because of the costs involved in mobilizing and demobilizing a field crew and the necessary vessels. Adding monitoring techniques or including floating stations to be allocated to investigations of specific anomalies may also be useful. For example, if a distinct biological community change is detected between two stations 2 km apart, it may be useful to place some floating stations at intervals to better define the boundary.

42. Considerations of modifying techniques, intensity, or frequency should also include reductions when appropriate. As monitoring continues, some questions will be answered or some concerns reduced, which will allow certain aspects of the program to be deemphasized. Periodic evaluation of

management information needs should be performed to determine what information is or is not being used to reach site-use decisions.

43. Equipment and techniques that can provide monitoring data with relatively short turnaround times are preferred. For example, traditional biological benthic grab samples can take months to process and interpret, whereas a benthic profiling camera may provide sufficient information in a matter of days or even hours.

Outlining the Program

44. The systematic approach toward designing a monitoring plan can be viewed in graphic form to better illustrate the flow of tasks required for the process (Figure 1). Each step incorporates the previously discussed tiered approach, including considerations of objectives and decision-making processes that are essential to completion of each task. The remainder of this section is devoted to outlining approaches to meeting the goals of each step in the planning process. Working through this process will help to ensure consideration of all pertinent aspects of a monitoring plan.

Step 1 - Designating site-specific objectives

45. Site-specific objectives and needs might include such factors as multiple/periodic versus one-time use of the site, seasonal timing and frequency of use, and use of the site for habitat creation or enhancement. In the case of seasonal timing and frequency of usage, questions about impacts reflect concerns over detrimental reductions and/or alterations of biological resources. Conversely, considerations of habitat creation or enhancement include levels of improvement of the site for beneficial resource utilization.

46. A particular concern relative to benthic communities is the timing of disposal with respect to recruitment patterns of the dominant biotic components of the system. Given a one-time disposal operation (over the course of a few weeks), timing of disposal should precede the peak recruitment period for the given region to facilitate more rapid recolonization and recovery of predisturbance conditions. If disposal is to occur continuously over longer periods of time, this consideration becomes a moot point. Knowledge of recruitment periods can, however, be used to predict recovery after disposal is completed.

47. The use of a site for habitat creation or enhancement has a different set of objectives, namely the goal of making the site more attractive to target organisms. In this case, considerations of physical and biological factors reflect levels of change required to meet the stated objective (e.g., creation of shallow-water habitat). A monitoring plan for this type of project must strive to document the beneficial aspects of the site.

Step 2 - Identifying components of the monitoring plan

48. An essential early step toward the design of a monitoring program should include the designation of physical, chemical, and biological parameters of concern. This task reflects predictions of the types of direct and indirect alterations that will result from disposal activities. Physical/chemical effects generally include those associated with sediment characteristics as well as spatial distribution of the material after placement. These factors represent both short- and long-term direct effects to the biota (e.g., resulting from changes in grain size and bottom topography). Alterations in water quality are generally short-lived, and while concerns over them may be justified during disposal, they are generally not considered as part of a long-term monitoring program.

49. Effects on biological resources are inherently related to the aforementioned physical/chemical alterations and must be considered as consequences of these changes. Immediate short-term effects include burial of benthic assemblages, which acts to reset the successional sequence of assemblage development, and alterations of sediment type, which can affect the type of assemblage that will recolonize the area.

50. Listing the potential areas of major concern is a useful way to visualize and organize a monitoring plan. This list should include information about suggested methods of measurement, if known. In many cases, the sequence of tasks will reflect a series of phases or subtasks of a program (e.g., physical mapping and delineation of the disposal mound, sediment characterization, and evaluation of water quality and biological resources). Often, techniques designed to measure physical parameters such as sediment dispersion can provide information from which biological monitoring can be planned (e.g., sample site selection). As biological impacts are closely tied to physical alterations, every effort should be made to coordinate physical and biological sampling efforts as much as possible in order to make full use of field collection efforts and reduce costs.

Step 3 - Predicting
biological responses and
developing testable hypotheses

51. This aspect of program development requires (a) quantitative estimates of alteration of each physical/chemical parameter of concern and (b) best available information on the levels of response of target resources to these alterations. By comparing these estimates, decisions can be made about critical threshold levels that could be used to develop criteria for a management decision on project continuation or cessation. Lunz and LaSalle (1986) provide a review of the literature on the physical/chemical alterations occurring around operating dredges and disposal operations, as well as available information concerning the effects of these alterations on fishes and shellfishes.

52. Specific information is needed on the range of a parameter within which a particular organism is capable of normal behavior. The upper limit of the range may be used as a threshold level at which a decision to alter operations must be made. The following example illustrates the process of defining a critical threshold and developing a testable hypothesis.

53. A species of mussel known to occur in the vicinity of the project area is known to be tolerant (exhibiting normal feeding behavior) of total suspended sediment (TSS) concentrations up to 500 mg/ℓ, above which it responds by valve closure for periods of up to 6 to 10 hr without undue harm. Levels of TSS during a disposal event are expected to be as high as 500 mg/ℓ at the surface and 1,000 to 2,000 mg/ℓ near the bottom within 500 m of the disposal site for up to 1 hr after each disposal event. Disposal events will occur about 10 to 12 hr apart. Given this information and the concern about mussels in the immediate vicinity of the disposal site, a monitoring effort might include periodic (e.g., every fifth disposal event) measurement of TSS concentrations 1 hr after an event to determine if site conditions do result in rapid settling of material and a return to ambient conditions (within 500 mg/ℓ) for a reasonable period of time between disposal events (to allow mussels periods of time to feed normally).

54. An example of a tiered approach to this issue would include specific conditions that would trigger more extensive monitoring of the situation, if warranted. For example, as long as levels of TSS return to less than 500 mg/ℓ within 1 hr after every fifth disposal event, no further action is taken. If, however, the concentration of TSS exceeds 500 mg/ℓ after 1 hr, a

second measurement is taken after 2 hr to assess the situation. If, after the second measurement, TSS concentrations remain above 500 mg/ℓ, the next disposal event is delayed for a period of time to allow TSS concentrations to return to ambient conditions for a period of a few hours. Note the use of specific TSS concentrations and time periods as critical threshold levels and the switch to more frequent sampling if the first threshold level is exceeded.

Step 4 - Designating
sampling design and methods

55. The design of a sampling program and choice of appropriate methods is as important as any of the steps so far discussed. The ways in which data are gathered (sampling methods) and analyzed (statistical methods) will determine their usefulness in drawing conclusions about the given study. Most importantly, the sampling design must be developed with a priori considerations of the type(s) of data that will be collected and the specific statistical analyses that will be applied. Again, it must be emphasized that the data collected must be applicable to addressing a specific question. Collecting data for no specific reason serves no purpose. The choice of sampling method or gear is also an important consideration in that the type of data obtained must be useful in addressing the specific question. For example, measurement of suspended sediment via gravimetric techniques (milligrams per litre) will do little to address a question about changes in optical turbidity and its effect on target organisms. Transmissometer or nephelometer measurements (measures of light penetration and scattering) would be more appropriate.

56. From a practical standpoint, however, logistical constraints must be considered when developing a sampling program. Considerations of sample size (areal coverage or volume), number of samples, and frequency of sampling, while important for statistical reasons, are often limited by constraints of handling and processing. Processing of benthic samples, including sorting and taxonomic identification, is very time consuming, thereby limiting the number of samples that can be reasonably taken and processed from both a cost and scheduling perspective. Too few samples, however, will seriously limit the confidence level of statistical analysis and thereby jeopardize the technical defensibility of the entire effort. Similar considerations are necessary with most types of samples, either physical or biological.

57. Considerations relative to statistical treatment also include selection of adequate control or reference sites and location of sampling

stations within sites. These types of concerns relate directly to the statistical test(s) to be applied. There is no simple way to determine either sample type or number of samples or the statistical methods to be used. A considerable amount of effort must, therefore, be expended to achieve a compromise between constraints on selection of appropriate sampling and statistical analyses.

58. A number of references (e.g., Cochran 1963, Green 1979) discuss the problems associated with sampling design and methodology and should be consulted prior to making decisions for a given study. At a minimum, knowledge about the limitations of a technique will help determine the degree of confidence in the results. Basic concepts of sampling design and commonly used sampling devices and methodologies are discussed in Fredette et al. (1990).

Step 5 - Designating management options

59. This step in the planning process involves decisions to be made in the event that threshold levels are exceeded. In a tiered program, these decisions are made at various tiers within the monitoring process but are, in each case, the result of exceeding a predetermined threshold. In the scheme of the hypothesis testing protocol, this process is the response to rejecting the null hypothesis (e.g., there is a significant difference between observed and predicted conditions).

60. In addition to identifying optional courses of action when a given threshold is exceeded, management decisions on available options once conditions of a given parameter return below critical threshold level are also needed. As previously discussed, supplemental monitoring (more frequent or more extensive sampling) of these parameters may be required to support a final management decision. The options themselves may include delays or discontinuation of operations and/or operational modifications that may alleviate the problem. Each option should be outlined and discussed during the planning process.

Examples of Tiered Monitoring Plans and Management Options

61. Examples of tiered monitoring plans for different combinations of native and disposal material sediment, with and without sensitive resources located nearby, are given in Figures 2-7. In all cases, only three tier levels are outlined. Additional tiers may be appropriate for several of the examples presented, and would generally include increased spatial and temporal

biological monitoring. Monitoring strategies and frequency, thresholds for management action, and management options are presented for each example. It is strongly emphasized that these cases are only examples of potential situations. Each actual case must develop its own monitoring strategy and management options based on site-specific factors.

62. Management strategy for each tier presents tools and sample spacing that could be used in each example. In several cases, multiple tools which perform similar tasks are listed; it is intended that one or possibly two tools be selected from the list, instead of using all those listed. For example, side-scan sonar (SS), the sediment-profiling camera (SPC), grab samples, cores, or cone penetrometers may all be used to map distribution of the fringing edge of the disposal mound sediments. From the list, the most efficient way to determine the distribution of disposal material should be selected, given the site conditions. Tool selection is based on a variety of technical factors discussed in Fredette et al. (1990), as well as the intended purpose of monitoring. In some instances, the only concern is development of a navigation hazard. In other cases, concern may be over navigation and degradation of surrounding biota. Further, navigation, general biota degradation, and specific nearby sensitive resources may combine to influence monitoring strategies.

63. Initial tier bathymetry for some of the examples is combined with Loran-C positioning. The ability to use Loran-C for first-tier monitoring will be site specific. In some locations Loran has sufficient absolute and repeatable accuracy for monitoring, while in other locations microwave positioning will be required. Details on the advantages and disadvantages of positioning systems can be found in Fredette et al. (1990).

64. As presented in these examples, monitoring frequency ranges from quarterly to yearly, although this range can be expanded in both directions. Monitoring frequency is strongly influenced by the specific level of concern. For example, a site where tier 2 monitoring has demonstrated movement of fine material toward an adjacent sensitive clam bed would require frequent biological sampling in tier 3. However, tier 3 sampling for nonsensitive biota adjacent to the site and/or navigation hazards would require much less frequency.

65. As stated previously, thresholds (triggers) for action should be identified early in the site selection and/or EIS process. Specific thresholds precipitating management decisions will help define the monitoring

strategy and frequency. Thresholds presented in these examples are purely hypothetical. They are intended only as examples of the type of threshold statements that must be formulated for site management. Site-specific thresholds can be developed from site designation documentation with advisory help from scientific experts.

66. Management options presented here are divided into two groups based on whether a threshold is exceeded. If critical thresholds are not exceeded, the management options are to continue monitoring at either the present or a reduced level or to cease monitoring completely. If a critical threshold is exceeded, the list of management options includes a variety of alternatives. The options listed in these examples are the most likely choices for a majority of disposal sites. One or multiple options may be selected, depending on site-specific conditions, ranging from simply increasing the monitoring level to termination of site use.

PART IV: SUMMARY OF MONITORING TOOLS AND TECHNIQUES

67. Monitoring of aquatic dredged material disposal sites may require a variety of physical and biological tools and techniques (Tables 1 and 2). Chemical monitoring is not discussed here since these guidelines do not include sites where chemically unsuitable material is placed. In the tiered approach discussed previously, the lower level tiers of monitoring efforts may examine primarily physical changes at a site. Changes in physical environment, such as mounding, can result in a navigation hazard or lead to changes in the biological community (e.g., burial), which would necessitate biological monitoring in advanced tiers. Design of the monitoring portion of a program must consider what equipment to use and at what spatial and temporal frequency to sample. These factors will be determined by the level of information required for the questions being addressed, given present technical, monetary, regulatory, and political considerations.

Physical Monitoring Tools

68. Physical monitoring tools can be broadly classified into several groups. Though not actually monitoring tools, navigation and positioning equipment represents the primary group. Effectiveness of all physical and biological sampling depends upon knowing the location of a sample relative to the disposal site. A variety of equipment types are available for locating a sample. Generally, more precise location requires more complex and expensive systems. Accuracies from ±1,500 to ±0.1 ft* are presently available. Accurate, low-cost satellite positioning may be readily available in the near future.

69. Equipment that measures bathymetry and ocean bottom configuration with acoustic energy is a second group. Fathometers (depth sounders) are most commonly used for bathymetry and can give elevations accurate to ±0.6 ft when corrections are applied for water-level and boat-level variations. Side-scan sonar has been used to map aerial distribution of sediment and surface bed forms for determining direction of sediment motion. Subbottom profilers have been used to examine internal mound and seafloor features.

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* To convert feet to metres, multiply by 0.3048.

70. A third group of physical instruments consists of those that directly sample sediment. Surface samples and cores can be collected with a variety of instruments. These range from grab samplers, which one person can operate to retrieve a small surface sample, to large vibracores, which return up to a 40-ft-long core through a disposal site. Usually, sands are the most difficult to penetrate, thus limiting tool selection.

71. A fourth group of tools for physical monitoring are those instruments that return data on site conditions remotely through the use of photography. These instruments, such as the sediment-profiling camera or video cameras attached to remotely operated underwater vehicles, have proven useful in delineating the outer fringes of disposal material, where necessary within a site. A collection of tools are available which can measure various engineering properties of disposal mounds in situ. Approximate sediment size, density, pore pressure, shear strength, settlement rates, etc., can be measured with these devices. Some of these are diver-operated, while others can be deployed from a ship.

72. Waves and current meters form the last group of tools that may be useful in physical monitoring. They are used to measure the driving forces for sediment transport. These instruments are costly to purchase and maintain. Records over long periods of time are difficult to obtain due to natural equipment failure and accidental destruction by fishing boats.

73. Spatial and temporal sampling intensity is generally low for tier 1 monitoring. As the tier level increases, frequency of sampling also increases. This applies to biological monitoring as well. Most sampling plans establish a regular or modified grid over the disposal study site for sample collection to ensure complete site coverage. Grid spacing, size, and shape depend on tier level, site conditions, and available resources. Tier 1 grids are typically widely spaced, with few sampling points covering the minimal area of anticipated impact. With increasing tiers, grid spacing is reduced, sampling frequency is increased spatially and temporally, and grid area may be increased. Temporal sampling frequency is highly dependent on the anticipated level of impact and the temporal physical and biological site variability.

Biological Monitoring Tools

Fish and shellfish sampling

74. Fish and shellfish are generally the animals of the greatest socioeconomic importance to individuals and agencies. However, obtaining quantitative information about a given species or assemblage presents more of a problem with mobile organisms such as fish and shellfish. Most sampling devices are selective in terms of size and, often, species, causing a bias in the resulting estimates of density, species diversity, or biomass. Considerable difficulty is often faced in obtaining replicate data, due to the variability in dispersion of individuals and their mobility. This results in great variability in both time and space. The combination of variability in abundance of fish and shellfish species and in sampling equipment and methods makes comparisons of data from various sources imprecise over large areas.

75. Sampling of nektonic organisms (fishes, shrimps, and crabs) is most commonly accomplished through the use of nets or traps of various types. Nets generally collect a greater diversity of organisms than do traps. Traps are usually designed to attract and capture a particular species (e.g., crab pots). The choice of sampling device(s) for monitoring depends on the type(s) of organism(s) of interest. Nets are either passive or active collectors of organisms. Passive nets are set in stationary positions, collecting organisms that become entangled (e.g., anchored gill net, hoop net, and fyke net) or entrapped within the confines of the netted area (e.g., fish traps) and may require extended deployment, in-place, and recovery periods. Active nets (e.g., otter trawls and purse seines) are towed through the water and produce immediate results.

Benthic infauna and submergent vegetation

76. Benthic infauna (particularly macrobenthos) and submergent vegetation are regarded as good indicators of environmental quality because of their sedentary nature, and thus their susceptibility to physical and chemical alterations. Because their sedentary existence requires a tolerance of short-term variation in environmental conditions, they reflect long-term integral conditions. In addition, they can be much more quantitatively and efficiently sampled. However, some disadvantages of macrobenthos as indicator species, when compared to fish, are that they have less life history information available, are more difficult to identify, and may not be as socially relevant

(although this may not hold true for certain macroinvertebrates deemed of importance to human beings, such as oysters and clams).

77. Benthic sampling devices come in a wide variety of designs and sizes. Many were developed and used on a regional basis and, as a consequence, are little known outside their respective areas. However, certain commonly used samplers have had widespread application.

78. A number of trawls and dredges have been designed and used as qualitative samplers of epifaunal and infaunal organisms in a variety of habitats, particularly in water deeper than 10 m (e.g., epibenthic sleds). These devices are best used for the purpose of general description of the assemblages present (species presence/absence). These devices are highly selective and are limited to collecting epifauna and shallow infauna, thereby providing little information on infauna at sediment depths greater than a few centimetres.

79. Grab samplers and box corers are the tools of choice for quantitative sampling of sessile epifauna and infauna (to the depth excavated by the sampler). Some of the more commonly used grabs include the Petersen, van Veen, Ponar, Ekman, and Smith-McIntyre grabs. These samplers all basically operate as mechanical scoops that, when triggered, remove a semicircular parcel of the bottom substrate. Typically these samplers collect material representing 0.02 to 0.5 sq m of surface area and penetrate to sediment depths ranging from 5 to 20 cm. Vertical sectioning, which is generally more quantitative than a basic grab, is also possible with some, such as the Reineck and Gray-O'Hara box corers.

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Table 1

Summary of Physical Monitoring Tools

Tool	Function	Regular or Special Use	Cost	Usable Data Return Time	Ease of Data Interpretation	Data Collection	Limits	Miscellaneous
Loran-C	Positioning	Regular	Low	Fast	Easy	In-house	Low accuracy	Signal interference can be local problem
Short-range microwave	Positioning	Regular	Moderate/ high	Fast	Easy	In-house/ contract	25-mile (40-m) limit; setup required	Accurate to ±3.0 ft (±0.9 m)
Total stations	Nearshore position and bathymetry	Special	Moderate/ high	Moderate/ fast	Easy	In-house/ contract	2.5-mile (4-m) offshore limit	Very accurate (±0.1 ft (0.03 m)); automation affects processing time
Global positioning system (satellite)	Positioning	Special (regular after 1992)	Low/ moderate	Slow/ moderate	Easy/ hard	Contract	Limited use until all satellites deployed	Postprocessing of data required for maximum accuracy
Depth sounders (Fathometers)	Bathymetry	Regular	Moderate	Slow/ moderate	Easy	In-house/ contract	Accuracy to ±0.7 ft (±0.2 m)	Require correction for accurate results
Swath survey Fathometers	Bathymetry	Special	Moderate/ high	Slow/ moderate	Easy	In-house/ contract	Useful only in low-energy conditions	
Stationary bathymetric systems	Bathymetry	Special	Low/ moderate	Moderate/ fast	Easy	In-house	Limited spatial coverage	Sonic altimeters; reference rods
Side-scan sonar	Mapping fringe bed forms	Special	Moderate	Fast	Hard	In-house/ contract	Useful only if disposal/native material different	Interpretation requires training
Subbottom profiler	Internal structure compaction	Special	Moderate	Fast	Hard	In-house/ contract	Trained interpreter required	Special models are useful in sand/gravel
Grab sampler	Surface sediment samples	Regular	Low	Fast	Easy	In-house	Surface sample only	Detailed information requires lab work

(Continued)

Table 1 (Concluded)

Tool	Function	Regular or Special Use	Cost	Usable Data Return Time	Ease of Data Interpretation	Data Collection	Limits	Miscellaneous
CS^3 and Gamma sled	Mapping mound fringe	Special	High	Moderate/ fast	Moderate	Contract	Dissimilar native/ disposal material required	May have more use in contaminated sites
Shallow penetrating cores	Mapping mound fringe; sediment properties 0 to to 10 ft (3 m)	Special	Low/ moderate	Slow/ moderate	Easy/hard	In-house/ contract	Difficult to penetrate sand/gravel	Cost varies--box corer, gravity, piston, diver assistance
Deep penetrating cores	Investigating sediment properties 0 to 40 ft (12 m) below seafloor	Special	High	Slow/ moderate	Easy/hard	In-house/ contract	Costly, big mobilization effort	Vibracores, drill rigs
Sediment-profiling camera	In situ sensing of sediment/benthos; map fringe	Special	Moderate/ high	Moderate/ fast	Easy/hard	Contract	Difficulty penetrating sands	Excellent reconnaissance tool, especially for benthic data
Video/remotely operated underwater vehicles	Mapping mound fringe, bed forms	Special	Moderate/ high	Moderate	Easy	Contract	Need clear water; positioning difficult	
Airborne remote sensing	Shoal measurements, bathymetry	Special	Low/ high	Moderate/ fast	Easy	Contract	Need clear water; new technique with potential	Electromagnetic profilers for cloudy water
Engineering properties	Measurement of geotechnical properties	Special	Low/ moderate	Moderate/ fast	Easy/hard	In-house/ contract	Each tool specific to one measurement	Variety of tools; cost savings potential
Current meters	Current speed and direction	Regular	High	Slow	Easy/hard	Contract	Vulnerable to loss/ damage	Variety of types
Drogues (seabed drifters)	Current tracking (direction)	Special	Low	Moderate	Easy	In-house	Limited to nearshore for collection	Transponders can be attached for tracking

Table 2

Summary of Sampling Characteristics of Benthic Sampling Devices

Gear	Weight*	Sample Width m	Sample Area m	Quantitative**	Depth of Sample (Firm sand)†	Deposit†† Firm Sand	Deposit†† Mud	Sea Depth††,‡ Shallow	Sea Depth††,‡ Shelf	Sea Depth††,‡ Deep Sea	Different Sea Conditions‡‡	Ship Size§
Macer-GIROQ sampler	H	0.5		Q	0	+	+	+	+			SML
Epibenthic sled (Hessler and Sanders)	H	0.8			0	+	+			+		ML
Epibenthic sledge (Alfred et al.)	H	2.3		SQ'	0	+	+			+		ML
Rectangular dredge	L	0.3-1.3			0	+	+	+	+	+	+	SML
Small biology trawl (Menzies)	L	1.0			0	+	+	+	+	+		ML
Anchor dredge (Forster)	L	0.5		SQ'	3	+	+	+	+	0		SM

(Continued)

Source: Eleftheriou and Holme 1984.

* Total weight (with any additional weights included): L, <100 kg; M, 100-200 kg; H, >200 kg.

** Codes are Q, quantitative; SQ, semiquantitative; SQ', semiquantitative if odometer wheel fitted.

† Penetration of sampler into firm sand: 0, surface sample only; 1, 1- to 10-cm penetration; 2, 10- to 20-cm penetration; 3, >20 cm penetration; M, above penetration depths but in soft mud only.

†† Codes are +, suitable; blank, possible application; 0, unsuitable.

‡ Shallow, diving depth (i.e., <30 m); shelf, 30-200 m; deep sea, >200 m (i.e., slope and abyss) (", from submersible).

‡‡ Sea conditions (most sampling gear cannot be used under severe conditions of swell, waves, or currents): +, instruments likely to obtain a sample under such conditions; 0, these instruments can be used only under calm conditions and/or absence of strong currents.

§ Size codes: S, launch with power hoist; M, trawler; L, large research vessel.

Table 2 (Continued)

Gear	Weight	Sample Width m	Sample Area m	Quantitative	Depth of Sample (Firm sand)	Deposit Firm Sand	Deposit Mud	Sea Depth Shallow	Sea Depth Shelf	Sea Depth Deep Sea	Different Sea Conditions	Ship Size
Anchor dredge (Thomas)	L	0.6			2	+	+	+	+			SM
Small anchor dredge (Sanders)	L	0.29		SQ	1	+	+	+	+	0		SM
Anchor dredge (Sanders et al.)	H	0.57		SQ	2	+	+		+	+		ML
Anchor-box dredge	H	0.5	1.33	SQ	1	+	+		+	+		ML
Petersen grab	L		0.1*	Q	1	0	+	+	+		0	SM
Campbell grab	H		0.55	Q	2	+	+		+	+		ML
Okean grab	L		0.08*	Q	1	+	+	+	+	+		SML
van Veen grab	L		0.1*	Q	1	+	+	+	+		0	SM
Ponar grab	L		0.055	Q	1	+	+	+	+	0		SM
Hunter grab	L		0.1	Q	1	+	+	+	+	0		SM
Smith-McIntyre grab	L		0.1	Q	1	+	+	+	+			SM
Day grab	L		0.1	Q	1	+	+	+	+			SM

(Continued)

* Other sizes available.

(Sheet 2 of 4)

Table 2 (Continued)

Gear	Weight	Sample Width m	Sample Area m	Quantitative	Depth of Sample (Firm sand)	Deposit Firm Sand	Deposit Mud	Sea Depth Shallow	Sea Depth Shelf	Sea Depth Deep Sea	Different Sea Conditions	Ship Size
Orange-peel grab	M		Various	Q	1	+	+	+	+	+	+	ML
Baird grab	L		0.5	Q	2	+	+	+		0	0	SM
Hamon grab	H		0.29	SQ	2	+	+	+	+			ML
Holme grab	M		2 x 0.05	Q	1	+	+	+	+			M
Shipek grab	L		0.04	Q	1	+	+	+	+	0		SM
Birge-Ekman grab	L		0.04	Q	M1		+	+	+			SM
Reineck box sampler	H		0.06*	Q	3	+	+	+	+	+		ML
Lubs sampler	M		0.06-0.25	Q	M2		+		+	+		ML
Haps corer	L		0.015	Q	M3		+	+	+			SM
Knudsen sampler	M		0.1	Q	3	+		+	+	0	0	SM
Suction sampler (True et al.)	L		0.1	Q	3	+		+	+	+"	0	SM
Suction sampler (Kaplan et al.)	L		0.1	Q	3	+	+	+	0	0	0	S
Suction sampler (Thayer et al.)	L		0.07	Q	3	+	+	+	0	0	0	S

(Continued)

* Other sizes available.

Table 2 (Concluded)

Gear	Weight	Sample Width m	Sample Area m	Quantitative	Depth of Sample (Firm sand)	Deposit Firm Sand	Deposit Mud	Sea Depth Shallow	Sea Depth Shelf	Sea Depth Deep Sea	Different Sea Conditions	Ship Size
Flushing sampler (van Arkel)	L		0.02	Q	3	+	+	+	0	0	0	S
Diver-operated suction sampler (Barnett & Hardy)	L		0.1	Q	3	+	+	+	0	0	0	

(Sheet 4 of 4)

Step 1

Designation of Site-Specific
Managerial Needs and
Objectives

Step 2

Identification of Physical and Chemical
Parameters and Biological Resources
Which May be Affected

Step 3

Prediction of Biological Responses to
Environmental Alterations at the Site
and
Development of Testable Hypotheses
Based on Predictions of Unacceptable
Environmental Thresholds

Step 4

Designation of Sampling Design
and Methods

Step 5

Designation of Management Options
Given Unacceptable Levels of
Alterations

Figure 1. Generalized step-wise procedure
for outlining a monitoring program

Disposal/Native Material = SAND/SAND — **Sensitive Resource Nearby = NONE**

Monitoring Strategy	Monitoring Frequency	Predefined Threshold for Action	Management Options: Threshold Not Exceeded	Management Options: Threshold Exceeded
TIER 1 Bathymetry, coarse grid (Fathometer, Loran-C)	Postplacement yearly	Mound height within 5 ft of navigation depth hazard.	* Stop monitoring. * Continue monitoring at same level. * Reduce monitoring.	* Move/rotate disposal points within site. * Increase level of monitoring. * Use dispersed disposal. * Limit quantity of material. * Move/redredge material. * Cease site use.
TIER 2 Bathymetry, fine grid (Fathometer, microwave)	Yearly	Mound within limits of navigation hazard.		
TIER 3 Bathymetry, fine grid (Fathometer, microwave)	Quarterly	Mound forms definite hazard to navigation.		

Disposal/Native Material = SAND/SAND — **Sensitive Resource Nearby = YES, Surf Clam Bed**

Monitoring Strategy	Monitoring Frequency	Predefined Threshold for Action	Management Options: Threshold Not Exceeded	Management Options: Threshold Exceeded
TIER 1 Bathymetry, coarse grid (Fathometer, microwave) Current meter	Postplacement semiannually	1) Mound height within 5 ft of navigation hazard and/or 2) 10% of original mound volume lost from site and/or 3) Currents predominantly toward clam bed.	* Stop monitoring. * Continue monitoring at reduced level. * Continue monitoring at same level.	* Increase level of monitoring. * Move/rotate disposal points within site. * Use dispersed disposal. * Limit quantity of material. * Change timing of disposal. * Move/redredge material. * Construct underwater contaminant berm. * Cease site use.
TIER 2 Bathymetry, (Fathometer, microwave), fine grid (incl. clam bed) Current meter(s) Grab samples on mound and clam bed Grabs/cores/penetrometer to map mound fringe and accumulation in clam bed (sand tough to penetrate)	Semiannually to quarterly	1) Mound at limit of navigation hazard and/or 2) Increase in fine sediment content of clam bed (winnowing of mound) approaches hazard level and/or 3) Rate of sand accretion in clam bed approaches limit of recovery from burial.		
TIER 3 Bathymetry, (Fathometer, microwave) fine grid (incl. clam bed) Current meter(s) Sample clam population Grabs/cores/penetrometer to map fringe of mound and accumulation in clam bed	Semiannually to quarterly	1) Mound forms definite navigation hazard and/or 2) Clam mortality imminent from fine sediment increase and/or 3) Clam mortality imminent from burial.		

Figure 2. Monitoring strategies and management options when disposal material is sand and native material is sand

Disposal/Native Material = MUD/SAND

Sensitive Resource Nearby = NONE

Monitoring Strategy	Monitoring Frequency	Predefined Threshold for Action	Management Options: Threshold Not Exceeded	Management Options: Threshold Exceeded
TIER 1 Bathymetry, coarse grid (Fathometer, Loran-C) Grab samples around site perimeter	Postplacement semiannually	1) Mound height within 5 ft of navigation hazard and/or 2) 10% of original mound volume lost from site and/or 3) Doubling of fines content of surrounding sands.	* Stop monitoring. * Continue monitoring at reduced level. * Continue monitoring at same level.	* Increase level of monitoring. * Move/rotate disposal points within site. * Use dispersed disposal. * Limit quantity of material. * Change timing of disposal. * Move/redredge material. * Construct underwater contaminant berm. * Limit type of material. * Cap mound. * Cease site use.
TIER 2 Bathymetry (Fathometer, microwave), fine grid (incl. adjacent areas) Current meter(s) Subbottom/geotechnical tools to measure compaction SSS/SPC/grabs/cores/penetrometer to map mound fringe Recon SPC/grabs/cores in adjacent benthic communities	Semiannually to quarterly	1) Mound at limit of navigation hazard and/or 2) Increase in fine sediment resulting in some stress to adjacent benthic community and/or 3) Rate of burial resulting in some stress to adjacent benthic community.		
TIER 3 Bathymetry, (Fathometer, microwave) fine grid (incl. adjacent areas) SSS/SPC/grabs/cores/penetrometer to map mound fringe Analysis of adjacent, stressed benthic communities - BRAT Current meter(s) Subbottom/geotechnical tools to measure compaction	Semiannually to quarterly	1) Mound forms definite navigation hazard and/or 2) Benthic community highly stressed from increase in fines and/or burial.		

Figure 3. Monitoring strategies and management options when disposal material is mud and native material is sand, and no sensitive resources are nearby

Disposal/Native Material = MUD/SAND

Sensitive Resource Nearby = YES, Surf Clam Bed

Monitoring Strategy	Monitoring Frequency	Predefined Threshold for Action	Management Options: Threshold Not Exceeded	Management Options: Threshold Exceeded
TIER 1 Bathymetry, fine grid (Fathometer, microwave) Current meter SSS/SPC/grabs/cores/penetrometer to map mound fringe Grab samples in clam bed	Postplacement Quarterly	1) Mound height within 5 ft of navigation hazard and/or 2) 10% of original mound volume lost from site and/or 3) Currents predominantly toward clam bed and/or 4) Doubling of fines content of clam bed and/or surrounding nonsensitive benthic community.	* Stop monitoring. * Continue monitoring at reduced level. * Continue monitoring at same level.	* Increase level of monitoring. * Move/rotate disposal points within site. * Use dispersed disposal. * Limit type of material. * Cap mound. * Limit quantity of material. * Change timing of disposal. * Move/redredge material. * Construct underwater containment berm. * Cease site use.
TIER 2 Bathymetry (Fathometer, microwave), fine grid (incl. clam bed and/or adjacent benthic communities) Current meter(s) Subbottom/geotechnical tools to measure compaction SSS/SPC/grabs/cores/penetrometer to map fringe of mound Recon SPC/grabs/cores in clam bed and/or adjacent benthic communities	Semiannually to quarterly	1) Mound at limit of navigation hazard and/or 2) Increase in fine sediment resulting in some stress to clam bed and/or adjacent benthic community and/or 3) Rate of sand accretion in clam bed/benthic community approaches limit of recovery from burial.		
TIER 3 Bathymetry (Fathometer, microwave) fine grid (incl. clam bed and/or adjacent benthic communities) SSS/SPC/grab/cores/penetrometer to map mound fringe Analysis of clam bed and/or stressed benthic community - BRAT Current meter(s) Subbottom/geotechnical tools to measure compaction	Semiannually to quarterly	1) Mound forms definite navigation hazard and/or 2) Clam bed and/or benthic community highly stressed from increase in fines and/or burial.		

Figure 4. Monitoring strategies and management options when disposal material is mud and native material is sand, and a sensitive resource is nearby

Disposal/Native Material = MUD/MUD — Sensitive Resource Nearby = YES, Unique Benthic Community

Monitoring Strategy	Monitoring Frequency	Predefined Threshold for Action	Management Options: Threshold Not Exceeded	Management Options: Threshold Exceeded
TIER 1 Bathymetry, coarse grid (Fathometer, microwave) Current meter	Postplacement semiannually	1) Mound height within 5 ft of navigation hazard and/or 2) 10% of original mound volume lost from site and/or 3) Strong currents dominate toward benthic community	* Stop monitoring. * Continue monitoring at reduced level. * Continue monitoring at same level.	* Increase level of monitoring. * Move/rotate disposal points within site. * Use dispersed disposal. * Limit quantity of material. * Change timing of disposal. * Move/redredge material. * Construct underwater containment berm. * Limit type of material. * Cap mound. * Cease site use.
TIER 2 Bathymetry (Fathometer, microwave), fine grid (incl. resource site) Current meter(s) SPC/cores/penetrometer to map mound fringe and accumulation on resource site	Semiannually to quarterly	1) Mound at limit of navigation hazard and/or 3) Rate of accretion in benthic community near limit of recovery from burial.		
TIER 3 Bathymetry (Fathometer, microwave) fine grid (incl. resource site) SPC/cores/penetrometer to map mound fringe Sample/analyze adjacent stressed benthic communities - BRAT Current meter(s)	Semiannually to quarterly	1) Mound forms definite navigation hazard and/or 2) Benthic community highly stressed from rapid accumulation of sediment.		

Disposal/Native Material = MUD/MUD — Sensitive Resource Nearby = NONE

Monitoring Strategy	Monitoring Frequency	Predefined Threshold for Action	Management Options: Threshold Not Exceeded	Management Options: Threshold Exceeded
TIER 1 Bathymetry, coarse grid (Fathometer, Loran-C)	Postplacement yearly	Mound height within 5 ft of navigation depth hazard.	* Stop monitoring. * Continue monitoring at same level. * Reduce monitoring.	* Move/rotate disposal points within site. * Increase level of monitoring. * Use dispersed disposal. * Limit quantity of material. * Move/redredge material. * Cap mound. * Cease site use.
TIER 2 Bathymetry, fine grid (Fathometer, microwave)	Yearly to semiannually	Mound with limits of navigation hazard.		
TIER 3 Bathymetry, fine grid (Fathometer, microwave)	Quarterly	Mound forms definite hazard to navigation.		

Figure 5. Monitoring strategies and management options when disposal material is mud and native material is mud

Disposal/Native Material = SAND/MUD

Sensitive Resource Nearby = NONE

Monitoring Strategy	Monitoring Frequency	Predefined Threshold for Action	Management Options: Threshold Not Exceeded	Management Options: Threshold Exceeded
TIER 1 Bathymetry, coarse grid (Fathometer, Loran-C) Grab samples around site perimeter	Postplacement semiannually	1) Mound height within 5 ft of navigation hazard and/or 2) 10% of original mound volume lost from site and/or 3) Doubling of sand content of surrounding mud.	* Stop monitoring. * Continue monitoring at reduced level. * Continue monitoring at same level.	* Increase level of monitoring. * Move/rotate disposal points within site. * Use dispersed disposal. * Limit quantity of material. * Change timing of disposal. * Move/redredge material. * Construct underwater contaminant berm. * Limit type of material. * Cease site use.
TIER 2 Bathymetry (Fathometer, microwave), fine grid (incl. adjacent areas) Subbottom/geotechnical tools to measure compaction SSS/SPC/grabs/cores/penetrometer to map fringe of mound Recon SPC/grabs/cores in adjacent benthic communities Current meter(s)	Semiannually to quarterly	1) Mound at limit of navigation hazard and/or 2) Increase in sand content resulting in some stress to adjacent benthic community and/or 3) Rate of burial resulting in some stress to adjacent benthic community.		
TIER 3 Bathymetry (Fathometer, microwave) fine grid (incl. adjacent areas) SSS/SPC/grab/cores/penetrometer to map mound fringe Sample/analyze adjacent stressed benthic communities - BRAT Current meter(s) Subbottom/geotechnical tools to measure compaction	Semiannually to quarterly	1) Mound forms definite navigation hazard and/or 2) Benthic community highly stressed from increase in sand and/or burial.		

Figure 6. Monitoring strategies and management options when disposal material is sand and native material is mud, and no sensitive resources are nearby

Disposal/Native Material = SAND/MUD

Sensitive Resource Nearby = YES, Unique Benthic Community

Monitoring Strategy	Monitoring Frequency	Predefined Threshold for Action	Management Options: Threshold Not Exceeded	Management Options: Threshold Exceeded
TIER 1 Bathymetry, fine grid (Fathometer, microwave) Current meter SSS/SPC/grabs/cores/penetrometer to map mound fringe Grab samples in resource area	Postplacement semiannually to quarterly	1) Mound height within 5 ft of navigation hazard and/or 2) 10% of original mound volume lost from site and/or 3) Currents predominantly toward resource site and/or 4) Doubling of sand content of adjacent unique benthic community.	* Stop monitoring. * Continue monitoring at reduced level. * Continue monitoring at same level.	* Increase level of monitoring. * Move/rotate disposal points within site. * Use dispersed disposal. * Limit type of material. * Cease site use. * Limit quantity of material. * Change timing of disposal. * Move/redredge material. * Construct underwater containment berm.
TIER 2 Bathymetry (Fathometer, microwave), fine grid (incl. adjacent resource) Current meter(s) Subbottom/geotechnical tools to measure compaction SSS/SPC/grabs/cores/penetrometer to map mound fringe Recon SPC/grabs/cores in unique benthic community	Semiannually to quarterly	1) Mound at limit of navigation hazard and/or 2) Increase in sand content resulting in some stress to adjacent benthic community and/or 3) Rate of sand accretion in clam bed approaches limit of recovery from burial.		
TIER 3 Bathymetry (Fathometer, microwave), fine grid (incl. adjacent resource) SSS/SPC/grabs/cores/penetrometer to map mound fringe Sample/analyze unique benthic community - BRAT Current meter(s) Subbottom/geotechnical tools to measure compaction	Semiannually to quarterly	1) Mound forms definite navigation hazard and/or 2) Benthic community highly stressed from increase in sand content and/or burial.		

Figure 7. Monitoring strategies and management options when disposal material is sand and native material is mud, and a sensitive resource is nearby